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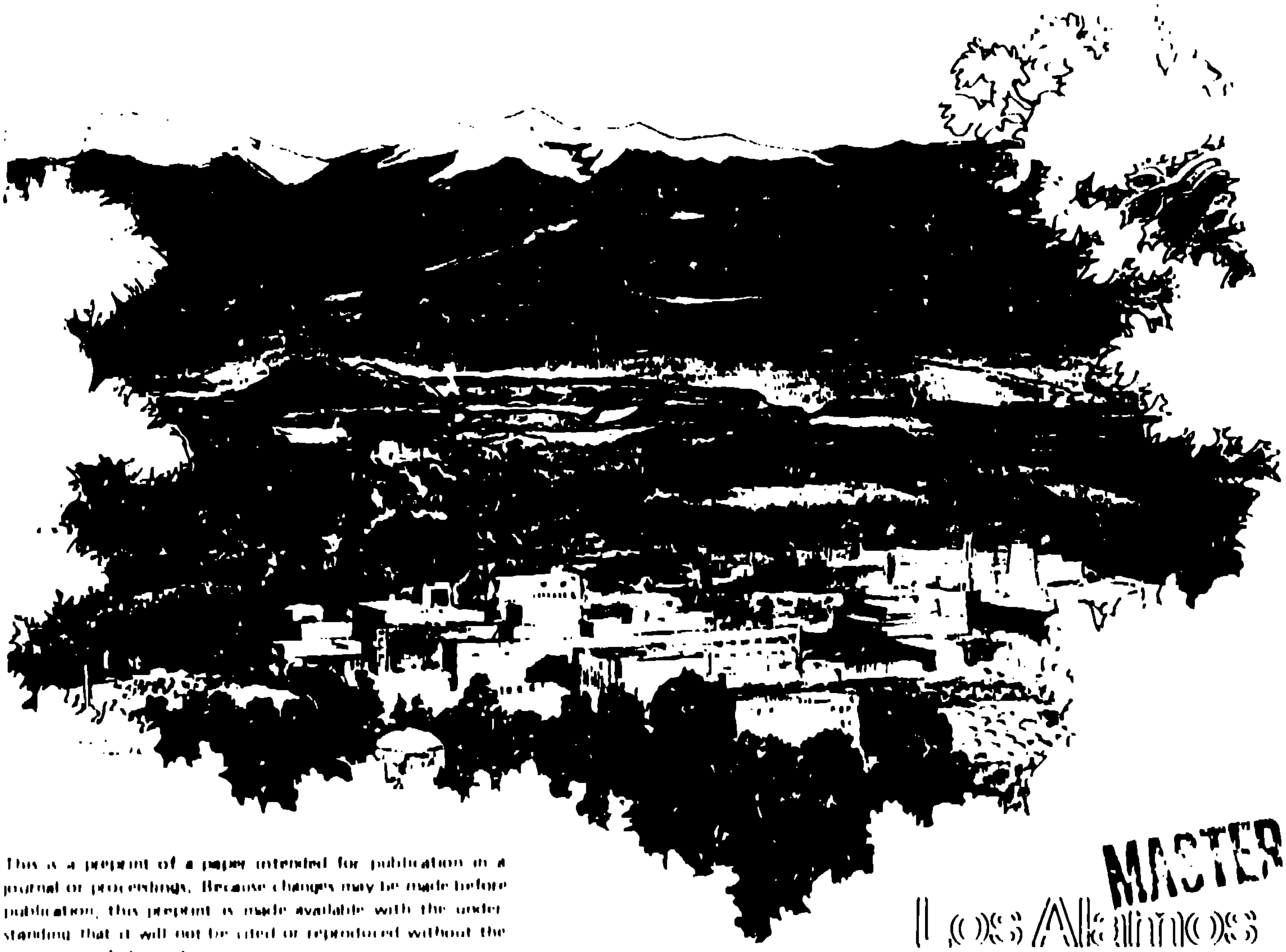

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ON DESIGNING A CONTROL SYSTEM FOR A NEW GENERATION OF ACCELERATORS*

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Abstract

A well-conceived plan of attack is essential to the task of designing a control system for a large accelerator. Several aspects of such a plan have been investigated during recent work at LAMPF on design strategies for an Advanced Hadron Facility control system. Aspects discussed in this paper include: identification of requirements, creation and enforcement of standards, interaction with users, consideration of commercial controls products, integration with existing control systems, planning for continual change, and establishment of design reviews. We emphasize the need for the controls group to acquire and integrate accelerator design information from the start of the design process. We suggest that a controls design for a new generation of accelerators be done with a new generation of software tools.

Introduction

This paper originated in discussions concerning control systems for the Advanced Hadron Facility (AHF) currently being investigated as part of the work of the Los Alamos Meson Physics Facility (LAMPF).

Since actual implementation of an AHF control system is several years in the future, our concerns focused on the global issues of control systems design, particularly as they applied to particle accelerators. We are well aware of the futility of speculating on future hardware technology. The exercise of writing this paper has helped to refine our ideas on control system design. We offer our insights for use by others who may be in a similar situation.

Our background includes experience with both the LAMPF and the Proton Storage Ring (PSR) control systems. The LAMPF system [1] design began in the late 1960's, and the PSR system [2] development began independently in 1978. Both systems are still in use and evolving. The difficulties we encountered when we considered merging the LAMPF and PSR control systems pointed out to us vividly the importance of standardization and integration at the earliest possible point in the design process.

We recognize that the controls group has a global responsibility for the functioning of the accelerator and must acquire and coordinate information from all the other accelerator groups as soon as possible.

We also recognize the need to integrate other, traditionally separate, activities into the control system and to do so from the beginning of the design process. The beam modeling process, in particular, should be made an integral part of an accelerator control system.

We emphasize these design aspects in the remainder of this paper. After briefly describing the Advanced Hadron Facility accelerator proposals, we discuss some of the important global aspects of accelerator control system design. Our final section deals with a possible approach to providing the integration and unification that is vital to the successful operation of a new generation of accelerators.

The Advanced Hadron Facility

As initially visualized [3], the accelerator for the Advanced Hadron Facility, then known as LAMPF II, was to use the 800-MeV, 1-mA, 120-Hz LAMPF linac as an injector to a 6-GeV, 144-mA, 60-Hz booster synchrotron. The booster would then inject beam into a 45-GeV, 32-uA, 3.33-Hz main synchrotron with a 50% duty factor. The facility was to be a kaon factory providing an array of light hadronic probes to investigate physical regimes beyond the standard model and to address the quark/gluon frontier.

The current AHF concept [4] is based on providing a combined kaon factory and a second generation spallation neutron source. The proposed accelerator plan is to accelerate the LAMPF beam to 2 GeV using a 1.2-GeV superconducting afterburner linac. This beam would then be used to inject a compressor ring (possibly five rings operating at 12 Hz) whose output would drive the spallation source. The output of the superconducting afterburner would also be used to inject the kaon factory synchrotrons. The synchrotrons would most likely include a 15-GeV booster and and a 60-GeV main ring. An accumulator ring and a stretcher ring might also be necessary.

The final design of the AHF will undoubtedly require an evolving sequence of accelerators, some built and commissioned separately, but all requiring coordinated timing and controls to operate successfully. Successful operation will not only include delivering the promised beam energies and intensities, but also limiting beam losses, which can result in unacceptable activation levels in a high intensity accelerator. The final design will also most likely allow for possible upgrades to the accelerators in both intensity and energy.

A brief description of proposed control system hardware for the AHF is given in [3]. Since the accelerators making up the AHF are extensions of existing technology, they present few new hardware controls problems. The AHF proposal does not, however, address the problem of designing a control system.

Aspects of Control System Design

The controls group is an organization that looks at the whole picture. It is uniquely suited to realizing the importance of integrating the various aspects of the accelerator design. It has the responsibility of providing links between the operator and the accelerator hardware.

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It also has responsibility for investigating the entire accelerator environment when it appears that one of these links has failed. In this section we discuss areas that must be considered in producing a design for an integrated accelerator control system.

Generic Control System Functionality

Control systems can be categorized by the levels of functionality they support. An analysis done recently at Los Alamos [5] identified the following seven levels needed for a full, automated control system.

1. Data acquisition -- Data describing the process state is collected through the control system.
2. Supervisory control -- The operator can control remote devices through the control system.
3. Model support -- A model of the controlled process is available for designing the process and for testing proposed changes to the process.
4. Continuous control -- Control loops are closed through the control system to provide steady state operation.
5. Sequential control -- The control system can automatically perform a series of actions to change the state of the controlled process.
6. Fault recovery -- Sequential control can be applied to automate fault recovery.
7. Optimization -- The control system can attempt to optimize the controlled process by changing continuous control and sequential control parameters automatically.

Current accelerator control systems implement at least data acquisition and supervisory control capabilities. Partial support for other levels is sometimes made available, but often only in a very ad hoc manner. We believe that the AHF control system should provide support for each of these levels in an integrated system that allows the capabilities of the levels to be added in an evolutionary manner. While we do not see an absolute requirement for totally automated control for the AHF, it seems clear that the necessary hooks should be present.

Model support is provided in nearly every accelerator control system, but usually not in an integrated manner. For example, at LAMPF a modeling program is run, a number is printed out or written down, and that number is later used to manually set a magnet power supply or for some other purpose. A state-of-the-art AHF control system should provide uniform access to modeling software and model derived data.

For many control systems, some amount of continuous control has been added as an afterthought as confidence grew in the reliability and stability of the control system and the data. An interesting implementation of closed loop control can be found in the Stanford Linear Collider control system [6]. The AHF control system should also provide closed loop control in an integrated manner.

Many machine optimizations are understood well enough to be performed in an algorithmic fashion. Other optimizations are done non-algorithmically -- for example, by an operator tweaking a magnet to get better performance. Representation and use of this form of knowledge will probably require some artificial intelligence (AI) capability. Some initial steps have been taken to link modeling with AI [7,8]. Machine reasoning has also been found to be of use in diagnosing malfunctions in complex control systems [9]. Based on these projected uses, we recommend that some support for eventually using AI functionality be integrated into the AHF control system from the beginning.

Identifying Information Sources

The generic functionality specified above for the AHF control system gives us a starting point for identifying the control system requirements. The first step is to identify the information needed to provide the desired functions.

Table 1 is a preliminary attempt to show the information required by each function. Two broad categories are used to

Information Required for Function:

	Equipment Information					Beam related Information		
Function:	Geometry	Access	Operation	Constraints	Faults	Design Parameters	Operating Parameters	Optimization Parameters
Data Acquisition		X	X					
Supervisory Ctl		X	X					
Modeling	X	X	X	X		X	X	
Continuous Ctl	X	X	X	X			X	
Sequential Ctl	X	X	X	X		X	X	
Fault Recovery	X	X	X	X	X	X	X	
Optimized Ctl	X	X	X	X	X	X	X	X

Table 1. Accelerator Information Needed for Generic Controls Functions

classify the information. Beam-related information includes design parameters obtained from modeling codes; operating parameters obtained from experience commissioning, tuning, and operating the facility; and optimization parameters which come from experiments exploring the machine's parameter space. Equipment-specific information is that which describes the details of individual devices that make up the facility. It includes device geometry (both location and configuration), the access mechanism and address for acquiring data from and controlling the device, operating instructions, constraints on using the device, and device fault handling.

Once the required information is identified, the next logical step is to determine what activities will supply that information.

Table 2 shows a list of eight accelerator-related activities that produce the information identified in Table 1. Note that the beam design, commissioning, and tuning activities all use modeling software to aid understanding and prediction of beam behavior. The tuning activity also includes accelerator physics experiments needed to optimize beam parameters and to investigate new operating modes. Note also that the design, installation, and commissioning activities will be repeated whenever the AHF is upgraded.

The importance of the design, installation, and tuning activities in generating information of interest to the control system is made abundantly clear by Table 2. The control system must be able to extract accelerator parameters generated in each of these phases as well as the accelerator parameters determined as part of tuning the machine. Note that design parameters (e.g., emittance) are not necessarily the same as the related commissioning or operating parameters. This distinction should be maintained within the control system.

An example of the importance of recording design information in a consistent, universally accessible manner occurred recently at LAMPF. The operations group had a request to accelerate the H+ to less than the 800 MeV maximum energy of the linac (an unusual operating mode for H+). This is done by allowing the beam to drift in the later portion of the linac, but no one knew how to set the quadrupole magnets in the drift region. Some searching produced an old program listing containing "magic" numbers for computing the quadrupole settings. The computations were redone, producing what we hope are the correct values. It is possible that this exercise could have been avoided if the relevant design information had been integrated into the control system.

User and Environmental Requirements

The activities identified in Table 2 also point to the four major classes of control system users. Note that a given person may perform more than one of these roles.

- Accelerator physicists
- Equipment engineers
- Operations staff
- Controls staff

The information the users need and the activities in which they are involved help to identify the requirements they add to the control system.

Accelerator physicists use the control system to compare the actual and theoretical behavior of the accelerator, using both experimental data and the modeling software. They are interested in the accelerator design, commissioning, and tuning activities. They want a flexible, efficient control system with a simple and consistent operator interface. Because of the long intervals between tunes for most large machines, an operator interface that is easy to remember or relearn is particularly valuable.

Equipment engineers design, implement, and maintain the hardware that makes the accelerator work. They use the control

Information Supplied by Activity:

Activity:	Equipment Information: Geometry	Access	Operation	Constraints	Faults	Beam related Information: Design Parameters	Operating Parameters	Optimization Parameters
Beam Design	X					X		
Equipment Design	X		X	X	X			
Installation	X	X		X				
Commissioning	X		X	X	X		X	
Tuning							X	X
Surveillence			X		X		X	X
Trouble shooting			X	X	X		X	
Maintenance	X	X	X	X	X			

Table 2. Accelerator Control System Information Sources

system to monitor and diagnose the hardware. They often want hardware control at a remote location and the ability to operate subsystems independently.

The operators are concerned with all aspects of running the accelerator: commissioning, tuning, and production. They need to be able to put the accelerator in a known state and keep it there. They must have rapid response to fault indications and the support of the control system in dealing with them. They want a control system that is efficient and has a consistent operator interface. The control system may also be used by the operations staff for training purposes.

The controls staff most often uses the control system to test software and to diagnose system-wide problems. They need access to all hardware and software levels of the system.

Particle accelerators used for physics research are always in a state of development. The control system must be flexible enough to cope with this constant change. This means not only adding new devices of a known type, but also adding previously unknown device types. This requirement has a large impact on the amount and kind of flexibility that is built into the control system.

An environmental requirement common to many accelerator control systems is the need to handle existing control systems in the new control system plan. This requirement arose at CERN with the SPS and has now arisen with LEP. It will certainly be a concern at LAMPF. The options are

- o To extend an already existing control system if the original is robust enough;
- o To provide communications between the old and new systems with no attempt at integration (the current LAMPF/PSR solution);
- o And to provide a mechanism to allow the long-term convergence of the two control systems (the current SPS/LEP approach [10]).

Standards and Integration

The previous sections dealt with possible sources of requirements. These requirements must be collected, their implications dealt with, and their conflicts resolved, before an integrated control system environment can be established and the process of control system design can begin. Standards for control system interfaces (hardware, software, and human) can be specified only after a consistent set of control system requirements has been established.

During the requirements review, the requirements should be evaluated for their feasibility, their impact on system performance, maintenance, cost, and reliability; and their contribution to system simplicity, modularity, and expandability. Meetings with interested users are, of course, necessary. We suggest assigning weights to various requirement characteristics to help in resolving conflicts. We also suggest that an external (at least to the controls group) review of the requirements be made. The external reviewers should include designers and users of other control systems.

Once the overall requirements have been formulated, the process of integration and standardization can begin. A control system design environment must be established and its use initiated. Easy, standardized mechanisms must be put in place to allow the acquisition of design information from modeling software, from computer-aided design (CAD) systems, from other databases, and possibly from project management (e.g., PERT) systems. One must also decide who will be permitted to modify the information preserved in this environment.

Beyond the design environment, standards must then be set for hardware interfaces, networks, and generic operator interface tools. The real test of integrating closed-loop control, modeling, and automatic sequencing and optimization can then be addressed.

Enforcement of standards poses serious administrative problems in some cases, but one person's failure to comply can become everyone's long term problem. Perhaps the most effective approach is to work hard at the beginning of the project to convince all parties of the value and importance of the standards. Collecting and making use of suggestions from all interested parties can be very effective. Reviews or walkthroughs, required as a regular part of the design and implementation process, can also be useful.

Conclusion

Throughout this paper we have emphasized the wide range of information that must be captured in a control system. We have also noted a need for a common environment in which integration can be accomplished. This information must be easily updated when new information becomes available, and the storage mechanism must be flexible enough to represent, and allow changes to interrelationships. The controls group must establish the environment in which this information can be gathered, stored, and tracked.

Without going into detail, we suggest that an object oriented programming system (OOPS) [11] provides the necessary mechanism to accomplish these goals. An OOPS allows the generalization of an accelerator database. In an OOPS implementation, specific devices inherit characteristics and methods (functions) associated with generic (prototypical) devices. An OOPS also provides mechanisms for establishing relationships between various pieces of information, thus forming a knowledge base.

A further possibility would be the use of a expert system development tool such as the Knowledge Engineering Environment (KEE) System [12] to support an object oriented programming system. The KEE system also contains a standardized graphics interface and an inference engine to allow mechanized reasoning about facts and relationships contained in the knowledge base. We believe this approach offers the needed control system integration and flexibility, and also allows the later introduction of AI techniques. We are currently investigating this possibility.

We have purposely not dealt with network design, operator interfaces, or hardware interface standards in this paper. We feel that such details should only be resolved when the control system logical structure and philosophy have been firmly established. We emphasize again that the controls team must be involved early in the accelerator design process in order to provide an integrated and flexible controls product.

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